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ART. XVIII.—*On the Growth, Treatment and Structure of some common Hardwoods.*

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(Government Research Scholar).

(With Plate XXI. and Seven Text Figures).

[Read 12th December, 1918].

One of the great surprises of the war has been the enormous consumption of timber, but before the war the need of timber was great, and steps were taken in many countries to have supplies for future use. At the present time many believe we are faced with a timber famine in the near future, unless steps are taken to avert it. But before we can do anything in the way of providing for the future, and before we can make a definite working plan, we must know what our forests are capable of yielding under efficient management.

In Australia we have no managed forests which we can study, and we have no forests of known age, and therefore in constructing any yield tables we have to devise some method by which we can arrive at approximate rates of growth, and from these construct yield tables.

Since the publication of my paper last year, on the rate of diameter growth of Mountain Ash (E. regnans), a paper has been published by the New South Wales Forestry Department on the rate of growth of four species of Eucalyptus.

The method adopted by the N.S.W. Department is based on Sir William Schlich's method. An average tree is selected, and the bole is cut into a number of equal lengths, and the number of rings counted at the end of each length. From these results graphs are constructed. Schlich's method is open to very serious objections. In the first place it is almost impossible to select an average tree for the purpose. In working on these trees one finds the greatest variation between two trees which externally look similar. Again every variation of the single individual is taken as typical of the forest as a whole, otherwise the study of a single individual is meaningless. The objection to this method is shown in Fig. 6 of Bulletin No. 13, N.S.W. Forestry Commission. A forest changes gradually, and hence any graph representing it must not show any irregularities. Another difficulty experienced is that of counting the rings after about 90 years.

In dealing with the forest, by taking the average of as many typical trees as possible, we naturally eliminate individual variations very largely. Nature varies widely, but it varies around a mean, and it is the mean I have attempted to get.

Since the publication of my paper on diameter growth, a further series of measurements have been taken, and the resulting curve is very little different from the former one. I have attempted to carry the measurements to 100 years, but the results have not been satisfactory. The distinction between autumn and spring wood is not at all clear. With our long growing season and favourable weather it is not surprising that the limits of the rings are ill defined.

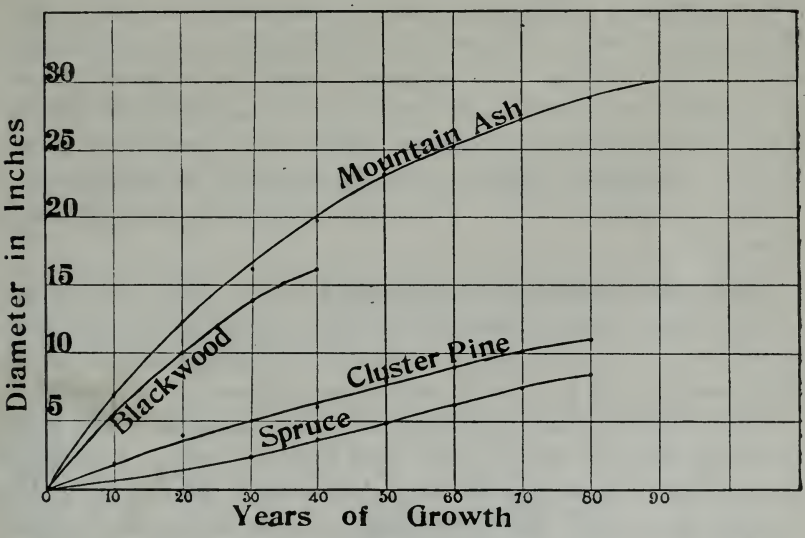


Fig. I.

The figures on which the curve for Mountain Ash (Eucalyptus regnans) is based were obtained in the Warburton area, while those for Blackwood (Acacia melanoxylon) were obtained at Beech Forest. Mountain Ash appears to grow slightly slower in Beech Forest, but the studies were not completed. The other curves are inserted for comparison. The figures for these curves were obtained as follow:—Cluster Pine, State Forest, Leiria, Portugal, quoted in a paper at British Association, 1914, by E. D. Hutchins, and published in "Australian Forestry." Spruce, from "Farm Woodlot," by Cheney.

On comparing the graphs it will be noted that the curves for Mountain Ash and Blackwood differ widely from the others.

It will be noted that the curves for local trees indicate a very rapid growth from the commencement. Professor Masson has kindly pointed out that the curve for Mountain Ash is a mass action curve, and that this particular curve gives a remarkable set of constants. The question of growth curves cannot be discussed here, but suffice it to say that the Eucalypt appears to be anomalous. In general it may be said that the growth curve contains a point of inflexion—the gradient is at first increasing and subsequently decreasing. It is interesting to notice that Blackwood, an associate of Mountain Ash, has the same type ot graph. Pinus insignis has a similar graph. Blackwood has been reputed a slow growing tree, but there is no evidence of this. It will be seen that good cabinet timber could be grown in 40 years. This rapid increase of diameter materially affects the management of the forest. It has ceen frequently stated in the press that we can regrow our forests in 40 years, but a detailed study of the forest fails to reveal any evidence of this. It is said that Mountain Ash will grow a butt of from 30 inches in 40 years. Individuals may do this, but we are concerned with the average over a wide area.

If we apply Schneider's formula $p=400/d.n$, where $p=$ rate per cent. at which wood is being produced, $d=$ diameter and $n=$ number of rings in the last inch, we find that in Mountain Ash at the 80th year, $p=1.9\ \%$. Under skilful management it is more than probable that this rate could be considerably increased. The fuller the crown kept on the tree, the more timber formed. A study of the big timber shows that the rate of increase is below 1 %, and it is more than likely that in the virgin forest increase is compensated by decay. The fixation of a diameter limit for felling without reference to rate of growth has no justification.

Height.—The heights were taken either with an Abney level and tape, or measured along the ground as the trees were felled. While it was a simple matter to get a curve for diameter growth, it was not an easy matter to get a curve for height. If we had patches of trees of known age the matter would have been simple. The objection to the Schlich method for obtaining a height curve has already been pointed out. The method adopted here was to establish a relation between diameter and height and, to plot these results, diameter against height. This was done for a large number of trees growing in close canopied high forest, but only normal trees were measured.

Since we have already a relation between diameter and age, we can now establish a relation between height and age from the graph of height and diameter, and plot the new curve. This method enables one to study the forest where, as yet, no felling is going on, and it embraces all trees from the youngest to the oldest. The method has no value when once age classes, growing in close canopied forest, are available, but these will not be available until perhaps a century or more has passed, and in the meantime we want some basis for our working plans. It may be objected that the method would break down owing to the variability in the height of the trees. However, under a given set of conditions the variations revolve round a mean, and in the case of Mountain Ash the given set of conditions are rather rigid. If we vary one of these conditions, Mountain Ash ceases to grow, and another eucalypt takes its place. Messmate (E. obliqua), grows under widely differing sets of conditions, but each set of conditions has its own height growth curve. The method adopted in this paper is applicable to any species growing under the same set of conditions in any one locality.

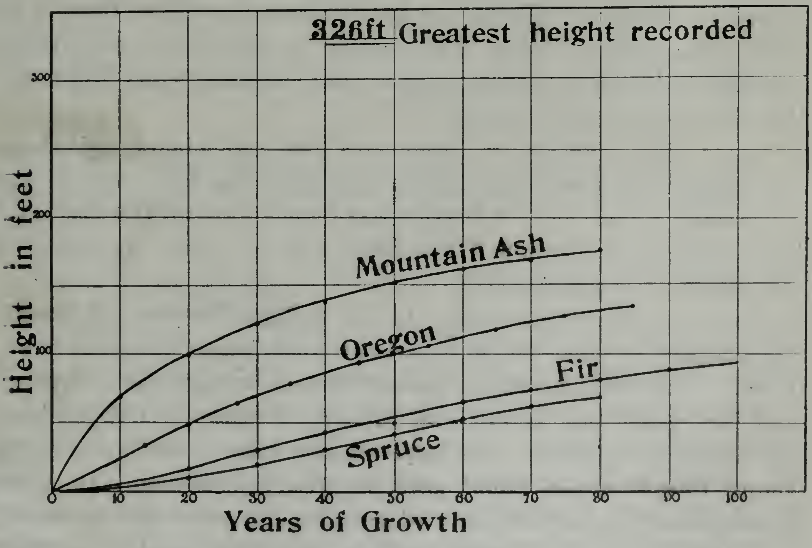


Fig. II.

The figures for height growth were obtained mainly at Powelltown, but measurements were also taken at Belgrave, Warburton and the Ada Creek. Observations have also been made at Upper Yarra, Cumberland Creek, and Beech Forest. In the latter forest, height generally appears lower than in the forests to the east of Melbourne. No satisfactory growth was available for Blackwood studies. The figures for the other curves, which are inserted for comparison, were obtained as follow:—Oregon from Maw's "Practice of Forestry," Fir from Fernow's "Economics of Forestry." The curve for Cluster Pine is slightly above that for Fir. It will be noticed that the curve for Mountain Ash is again a mass action curve. The eucalypt is here again somewhat anomalous, but the extraordinay rapid growth of many eucalypts during their early life has been pointed out in many parts of the world where they have been planted. Most plants grow very slowly during their early periods. The rapid growth in height partly explains why the eucalypt has no competitor in our forests. In "Australian Forestry," by E. D. Hutchins, it is recommended to underplant our Eucalypts with pines, but as these are light demanding, and as they are in general slower in growth than the Eucalypt, it is possible that the pines would be suppressed.

A good deal has been written about the height of our Eucalypts, and some very high figures have been given, but never proved. The two tallest I have seen were 261 and 249 feet. The official record is 326 feet. Whether or not we have the tallest trees is of little consequence. What does matter is which tree will reach merchantable size in minimum time, and in this respect Mountain Ash probably holds the record.

Taper.—The trunks of Mountain Ash are almost cylinders. The nearer the trunk approaches a cylinder the less waste in the conversion of the log. I have taken lengths up to 120 feet and have averaged the results. For every foot of ascent the taper is .36 inches of circumference.

Density of Trees per Acre.—In the managed forests of Europe the number of trees, on any area, at each decade is well known. Forestry has been practised under different systems for centuries, and the results are known and set out in tables. Graphs have been used only slightly. We have no such tables, nor have we any young forests which would give us this information. In those forests which we have, density of stocking has never been attended to. The aim of the forester must be maximum wood production per tree, combined with maximum number of trees per acre. The more trees per acre the smaller the crown, and hence the smaller the amount of wood formed. The converse is also true, within limits, but a large head is antagonistic to long clean boles. In order to construct a yield table this question of density per acre has to be settled. A study of the mature or over mature forest was first made in order to determine the number of mature trees per acre. The largest number of trees found per acre was forty-one, and the next best area averaged 39.5 trees per acre.

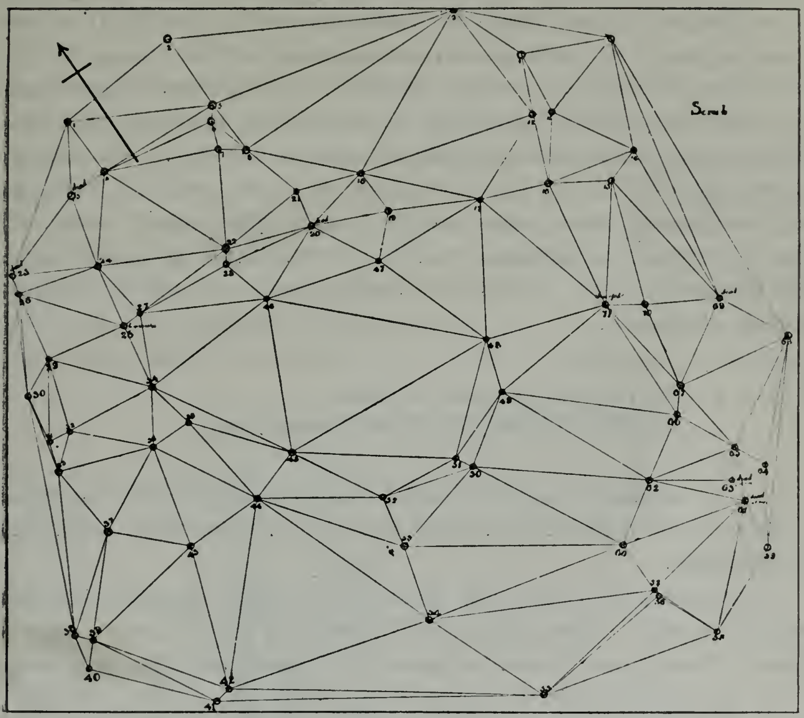


Fig. III.

Fig. III. is a survey of 1.7 acres at the Ada Creek, a tributary of the Latrobe River.

From the plan it will be seen that the trees are very unequally spaced, and that there are gaps in the forest. The crown canopy is not complete, and all the sun's energy is not being used for tree growth. From a long study of the crowns I came to the conclusion that a final spacing of 32 feet was suitable for these trees. This is not very great when we consider the height to which these trees grow. It may be objected that many trees, in fact numbers, do not form so big a crown. This is so; but these big trees with so small a crown are not thrifty trees, as they have not the leaf area to make a large amount of wood. These small crowns are due to the severe struggle for existence, but in a controlled forest the struggle would be relieved by thinning, and hence the trees would carry well formed crowns.

Spacing at 32 feet, and assuming the trees are so distributed that the crowns are hexagonal, there would be 49.13 trees per acre, or say 50.

Planting trees on the square does not fully utilise the ground. If we now work back we can ascertain how many trees there are in each crown class. The crown class preceding the 32 ft. class must be the 16 ft. class since trees are fixed in the one spot. If there are 50 trees per acre in the 32 ft. crown class, there must be 200 trees per acre in the 16 ft. class, that is by halving the diameter we increase the number of trees four times. The crown classes must be 32 ft., 16 ft., 8 ft., 4 ft., 2 ft., and 1 ft. When any one crown class passes into the next higher class, 3 out of every 4 trees are suppressed, and this is why thinning is necessary. The number of trees in any crown class may be found by the following expression.

$$q = ar^{n-1}$$

Where q = the required number of trees.
a = number of trees in the final crown class.
$r = 4$.
n = number of crown classes to and including class required.

From this we find that in the 1 ft. crown class there would be 51,200 trees.

It is customary to set out tables showing the number of trees at each decade. These tables are the result of experience. Nature does not work from decade to decade, but from crown class to crown class, and suppression is her mode of working. If we can conceive of a forest advancing from class to class, then we have a scientific basis for thinning. We have, however, to find some relation between the crown classes and the time taken to reach those crown classes. It has already been noticed that Mountain Ash starts with maximum effort in both diameter and height growth, and it might be supposed that the growth of the crown would be similar. However, the crown is not free to expand, but must struggle for its expansion, hence its curve of growth must differ from those of diameter and height. A study of the crowns suggested that the expansion of the crowns could be expressed as follows :—

$$t = ar^{n-1}$$

Where t = required age of a particular crown class.
a = known age of a particular class.
r = ratio.
n = number of crown classes concerned.

The study suggested that the value of r lay between 2 and 2.5. If the value be 2 then the expansion of the crown is a linear function of time. This is interesting when we remember the curves for both height and diameter. If the value of r be 2, then it takes double the time to double the crown, and when the crown reaches 32 feet in diameter there is an abrupt termination of lateral growth. This deduction is an objection to the suggested manner of expansion of the crown. Yet we are familiar with the apparent constancy of the size of the crown of mature trees. A detailed study of the sapling forests does not reveal any rapid expansion of the crown comparable to the growth in height and diameter. The relation between crown class and age seems to be that at about 8 years the 4 ft. crown class has reached maximum congestion and suppression occurs, and about 16 years the 8 ft. crown class is congested. From these figures we find that the 32 ft. crown class would be reached in 64 years. This seems somewhat

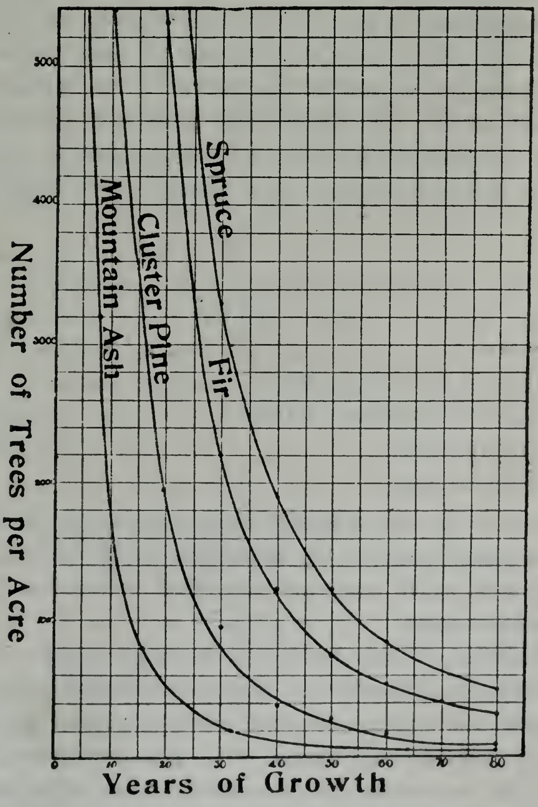


Fig. IV.

early, and therefore suggests that the value of r lies between 2 and 2.5, but it is certainly not greater than 2.5. It may be that the expansion of the crown is a linear function of time, but towards the end of the expansion the growth is slower, and hence the graph is no longer a straight line. It may be, however, that the graph is not linear, but during the earlier stages of crown expansion it approximates to a straight line. It is probably true that the value for r is the same for all close canopied pure forests. The difference between forests is due to the time taken to pass from one crown class to another. In other words, the forests differ in the intensity of the struggle for existence, and this intensity reaches a maximum, probably, in Mountain Ash forests. Since we know the number of trees in each crown class, and the age of each crown class we can plot the result.

The curve for Mountain Ash is a theoretical curve, the curves of Fir, Spruce and Cluster Pine are taken from tables, the sources of which have already been indicated. Very few tables were available for comparison, as our forestry literature is extremely limited. These curves, while giving the number of trees per acre at any particular year, are in reality the curves of the struggle for existence. It will be seen that the number of trees at any future period is equal to the present number of trees divided by the square of the quotient of the future age and present age. Expressing as an equation—

$$x=\frac{n}{\left(\frac{y}{z}\right)^2}$$

Where x = future number of trees.
n = present number of trees.
y = future age.
z = present age.

This seems to be the equation for the struggle for existence for any species competing for the same necessaries of life. The equation is only true until maturity is reached; after that the mortality is due to other causes.

From this view of the forest several suggestions stand out.

Each given set of conditions determines the ultimate size of any given species when grown in close canopy. Hence if the ultimate size of the mature tree varies with the environment, then the spacing of the trees when being planted out must be varied according to the site. No arbitrary distances, for all classes of soils, can be fixed. Yet this is what we are doing, and failing in a large number of cases.

From a former equation it will be found that the number of trees in the 1 ft. crown class would be 51,200. This figure has been regarded as altogether out of reason, but in a book just to hand, "Seeding and Planting in the Practice of Forestry," by J. W. Toumey, Professor of Silviculture at Yale, it is stated that the best results for oak and beech abroad are attained in direct seeding, which gives 50,000 seedlings or more per acre. Professor Toumey says: "We have failed to appreciate the necessity in most species for the germination of a large number of seeds per acre." For Mountain Ash probably 10,000 to 12,000 seedlings per acre may be regarded as satisfactory, but we are not getting this at present. We might even go as low as 4000, but the result would be very doubtful. The whole practice of forestry must be based on the survival of the fittest. The dangers of too open a forest cannot be too strongly emphasized, but this is not our subject. If we regard the forest as developing in crown classes, we have a basis for the practice of thinning. This forest practice is still debated, but when we remember that three out of every four trees are killed in every advance to the next crown class, thinning must be practised. Thinning merely anticipates nature and removes the trees which are being suppressed before they have injured the crown or form of the surviving trees. A full and well formed crown must be the constant aim of the forester.

Seasoning of Timber.—Since these experiments were commenced two new American books on the subject of kiln drying have reached here, and these deal fully with the subject. The type of kiln which has been adopted by U.S.A. Forest Service is undoubtedly efficient. The control of the humidity of the air in the kiln was obviously defective in our kilns here, and I worked upon the subject, but since these books have appeared there is no need to proceed further since the method adopted for controlling humidity is evidently successful. However, interesting points have arisen during the course of the year, which throw considerable doubt on the need for kiln drying on a large scale. With our dry summer climate, long hot days, and almost constant winds, we have a set of conditions at Melbourne most favourable for rapid drying. There is a belief that the place to season timber is where it is grown, but it remains for those who assert this to prove it.

Both in kiln drying and, in some cases in natural seasoning, the wood is first steamed in order "to open the pores," so that the wood will subsequently dry faster. As a matter of fact there are no pores in the wood to open, and hence from this point of view the work of steaming is useless. The only pores in our hardwood timber are at the ends, and these are already open. To test the efficiency of the process, 4 ft. lengths of 4 in. x 2 in. Mountain Ash were cut into 2 fts., and each weighed. One half was left in the air and the other half placed in a steam bath at atmospheric pressure. Pieces were left in the steam bath for periods ranging from 6 hrs. to 72 hrs. In all cases the weight of the piece when taken out of the bath and cooled was just about the same as when it went in, and this is what was expected. The pieces were weighed regularly, but both pieces, the steamed and the unsteamed, lost moisture at the same rate. The idea of the steam opening the pores of the wood is pure fallacy. However, after three months the steamed pieces began to shrink more than the unsteamed, and this went on until there was a marked difference in size between the two halves of each original length of timber. Although the steamed pieces were shrinking more than the unsteamed, yet both pieces were losing moisture at the same rate. A typical example may be given :—Nos. 7 and 8 were cut out of the same length of timber. No. 7 was steamed for 24 hrs., and No. 8 was not treated.

Date.	Weights of No. 7.	Weights of No. 8.
16.5.18	6 lb. 14½ oz.	6 lb. 13½ oz.
17.5.18	6 lb. 15 oz.	6 lb. 11 oz.
19.5.18	6 lb. 9 oz.	6 lb. 8 oz.
1.6.18	5 lb. 15 oz.	5 lb. 14½ oz.
15.7.18	5 lb.	5 lb.
9.9.18	4 lb. 11 oz.	4 lb. 10 oz.
7.11.18	4 lb. 7 oz.	4 lb. 6½ oz.

The shrinking of the steamed specimens is probably due to the steam slightly breaking down the structure of the wood. So far there does not appear to be any justification at all for steaming timber.

Many merchants stand the timber on end when naturally seasoning. The argument is apparently that the sap runs down the length of the timber. When the trees are felled sap does run out from the cut ends of the wood vessels, but this sap was in the cavity of the vessel. The moisture which is lost in seasoning is held in the walls of the cells. Hence this cannot run down the stem. It can only be lost by diffusion. To test the question, however, several experiments were carried out, but none of these justifies this end stacking. Lengths of 4 in. x 2 in. Mountain Ash were cut into sets of 1½ in., 3 in., 6 in. 1 ft., 2 ft., 4 ft. Four of these sets were made. The sides of the timber were paraffined so as to prevent all lateral evaporation, but the ends were left open. Two sets were placed vertically and two sets were laid horizontally. The vertical sets ought to have dried the more quickly, but this was not so. All four sets dried at about the same rate, the reason being that the moisture is lost by diffusion. The following graph shows the rates at which each length was drying.

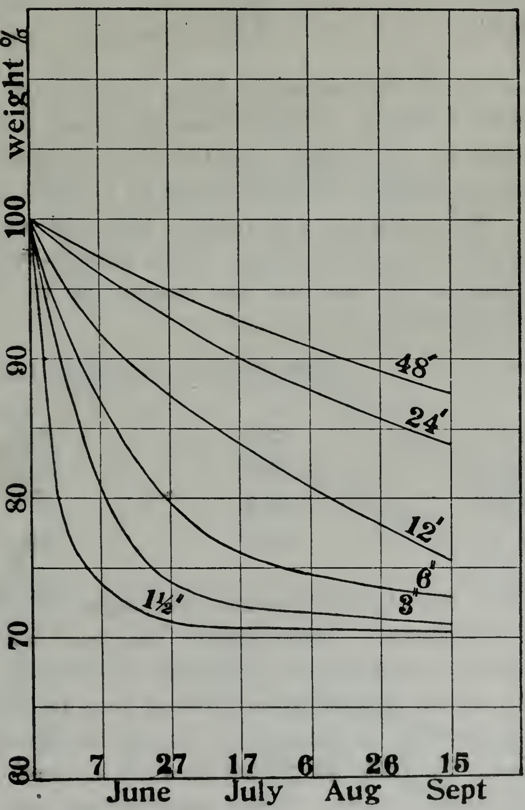


Fig. V.

Corresponding pieces which were not paraffined dried much more rapidly, showing that the loss of moisture is from the sides, not from the end of the timber. The theory of end drying was further tested by cutting a 10 ft. of E. goniocalyx into 2 5-fts., one being placed vertically and the other horizontally, the latter one resting on blocks on a table so that there was a free supply of air on all sides. The following table shows the results. Weights are expressed as percentages of the original weight.

Date.	Weight of Upright Beam.	Weight of Horizontal Beam.
	%	%
21.6.18	100	100
1.7.18	93.0	92.0
12.8.18	82.2	81.3
9.9.18	77.8	77.0
8.10.18	75.3	73.9
7.11.18	71.6	70.8

It will be seen that the horizontal beam has slightly the advantage in the rate of drying. Timber loses its moisture by diffusion through the sides of the timber, and therefore it does not matter how the timber be stacked provided there is a free supply of air all round it. The question was further tested by suspending a beam of 4 in. x 3 in. from the ceiling of the laboratory and taking the moisture content of the top and bottom of the beam each month. The result is as follows:—

Date.	Moisture Upper End.	Moisture Lower End.
	%	%
27.6.18	47.2	46.4
10.7.18	45.3	45.9
12.8.18	35.6	36.0
27.9.18	27.3	28.6

It will be seen that in this instance the lower end did have a slight excess of moisture. The question has been worked on in other ways, but no evidence is in favour of vertical or oblique stacking. The reason why timber so stacked does dry more quickly than timber in the rack is because the former is exposed freely to the air, while in the rack the timber is stacked in a mass where there is no circulation of air. It has already been mentioned that timber in long lengths loses moisture mainly through the sides, and not so much from the ends; but it was not known what part each surface took in drying. To ascertain this cubes were used from 1 in. up to 4 in. They were made in sets of 5, each set being cut from the same piece of timber. In all cases timber was selected which had the rings parallel to one side. In each set, one cube had all faces left clean, one had all six faces paraffined, and one had the radial faces left clean, one the tangential faces and one the cross section faces clean. In waxing them, the paraffin was heated to just above boiling point of water and then the face of the cube was brought into contact with the surface of the paraffin. When the paraffin set the process was repeated. This gave a very satisfactory result. In all the sets made the cubes which had the cross section faces left clean dried almost as quickly as the cube which had no paraffined faces. This is due to the vessels being small tubes running through the cube and therefore increasing the evaporating surface. This rapid drying from the ends does not extend far up the length, as will be shown later. It explains why logs left exposed to the sun split so badly at the ends.

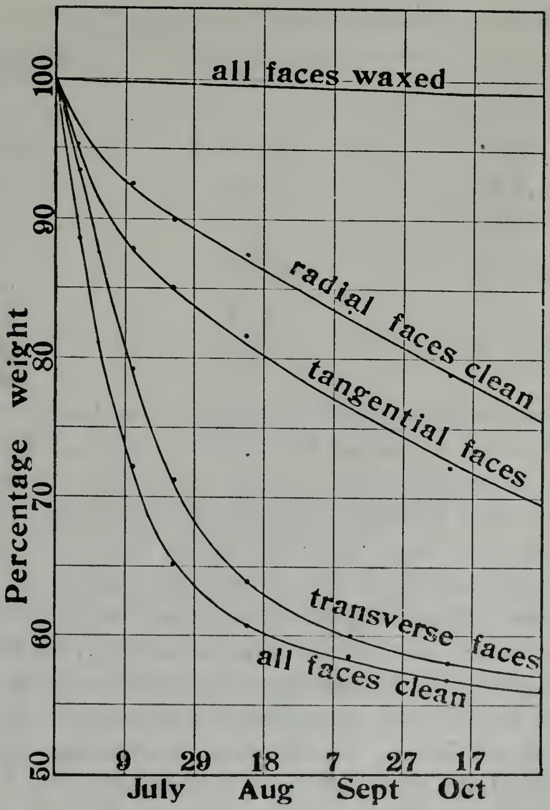


Fig. VI.

Fig. VI. gives a typical series of curves for the drying of the cubes by the various faces.

In all cases, except in the inch cubes, the tangential faces lost moisture more readily than the radial faces, but the difference from a commercial standpoint is negligible. The reason for the tangential faces losing moisture more rapidly is because of the large number of medullary rays, and these allow the moisture to escape. It is perhaps as well to explain that timber cut tangentially is said to be cut on the back, while if it is cut radially it is said to be cut on the quarter. As practically all the drying of a cube takes place from the transverse faces a comparison was made between a length of timber with all faces clean and a length which had the sides paraffined. Each piece was 4 ft. The loss of moisture from the paraffined piece has been very slow, and on a long length the influence of the ends would be negligible.

The percentage weights of the two pieces are as follow :—

Date.		Sides and Ends Clean.		Sides Waxed, Ends Clean.
		%		%
18.5.18	...	100	...	100
1.6.18	...	87.7	...	97.5
15.7.18	...	73.0	...	91.6
12.8.18	...	69.0	...	89.0
9.9.18	...	66.2	...	86.0
8.10.18	...	63.4	...	82.2
7.11.18	...	62.1	...	78.8

A test was made with both tangentially cut boards and radially cut boards to see if the loss of moisture was affected by lying the boards flat or standing them on edge. If drying be due to diffusion of moisture, then the manner of stacking ought to have no effect. It was ascertained later that some timber men in America prefer edge piling in the kiln to flat or ordinary piling. So far as can be ascertained, edge piling is not practised here. For the experiment the ends and two corresponding sides were paraffined. If the clean faces were placed vertically, then diffusion would be lateral, but if the clean faces were placed horizontally, then diffusion would be up or down. No difference in the rate of drying was observed either for the radially or tangentially cut faces. There may be, however, mechanical advantages in edge piling in a stack of timber which will affect the rate of drying, but this was not investigated.

It has become increasingly evident that the time required for natural seasoning is not nearly so long as usually stated, and hence a good deal of doubt is thrown upon the advisability of artificial seasoning on a large scale. Temperature and Circulation of Air are the two main factors in seasoning. But in the manner in which green timber is stacked in the timber yards there is no circulation of air in the stack, and hence drying can only go on from the ends, and these tend to crack badly. As timber dries by diffusion, then in such a stack the moisture must diffuse out from the ends, and hence it is no wonder that hardwood is said to be a slow timber in drying. If timber be filleted in the stack, that is if cross pieces are laid, some distance apart, across each layer of timber, and the next layer stacked on these, then there is an opportunity for circulation of air, and the winds would be responsible for this.

A stack of 6 fts. of 6 x 1 Mountain Ash was made in the laboratory, and fillets were placed between each layer. The boards are drying rapidly, but are not yet finished. The full results will be given in a paper to be published later, when a further test has been made outside with a larger stack.

The boards have dried rapidly, and a typical case is given below :—

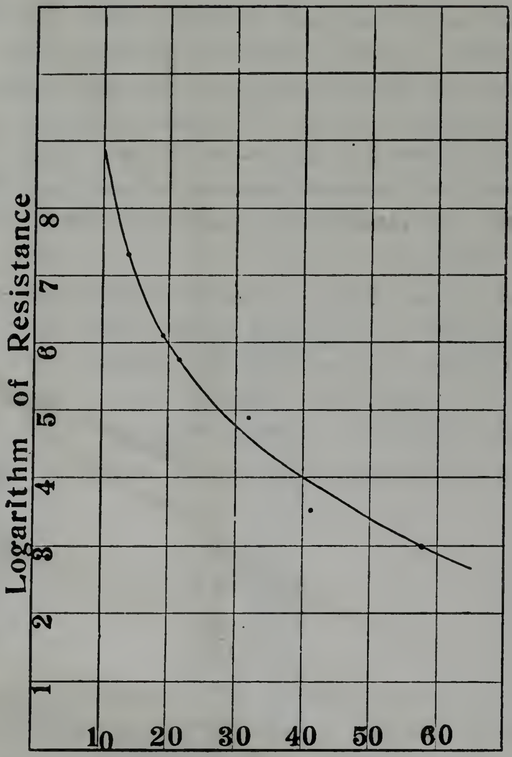
Date.	Weight.	Percentage Lost.
9.11.18	16 lb. 6 oz.	0
29.11.18	11 lb. 2 oz.	32.1
16.12.18	9 lb. 14 oz.	39.7
8.1.19	9 lb. 10 oz.	41.2
20.1.19	9 lb. 10 oz.	41.2

It will be seen that in two months the timber lost 41.2 %, and this must be regarded as very satisfactory.

During the summer and autumn Melbourne has ideal conditions for natural seasoning if the timber be properly stacked.

To be able to get the moisture content of timber readily is important, and Professor Laby suggested there might be a relation between moisture content and electrical resistance. The present method of finding the moisture content is not readily available for commercial use and therefore some simple method is necessary. The resistance was measured by a Megger. It was found necessary to plane up the surfaces of the timber to be tested, as the dry exposed faces greatly increased the resistance. The results are given in Fig. 7.

It will be seen that there is a close relation between moisture content and resistance. To be of any value, further experiments are necessary with regard to the direction in which the resistance is measured, species of timber, density of specimen, etc.



Percentage of moisture

Fig. VII.

Structure.—Only a few notes on the structure of Mountain Ash will be given, as a comparative study of the structure of our timbers is being carried on. The outstanding feature is the simplicity of its structure which in this respect is comparable to pine. The most notable feature is the area given over to water conduction. The vessels are elliptical, the major axis being directed radially. The largest major axis recorded is 0.4 mm., and the average works out at 0.253 mm. An interesting feature is the distribution of the vessels over the annual ring. They are not confined to the spring wood. A few experiments were made to determine the lengths of the vessels by the mercury method. It

Fig. A.—Very dense young forest of Eucalyptus regnans. Age 2 to 4 years.

Fig. B.—Mature forest of Eucalyptus regnans, averaging 39 trees per acre. Tallest tree 261 feet.